Multipacting Simulations for Power Couplers

Frank Krawczyk
Los Alamos National Laboratory

presented at the

Workshop on High-Power Couplers for Superconducting Accelerators

Jefferson Lab, Newport News, Virginia
October 30 - November 1, 2002

Multipacting

- Consideration of multipacting is important for new accelerator developments:
  - high current linacs:
    - higher power levels in power couplers
    - higher gradient structures
  - new $\beta < 1$ RF-structures
  - Increasing importance of 3D effects

Multipacting

Definition: *"An electron emitted from a wall under the influence of RF fields returns to its origin in an integer number of RF-cycles. The impact creates more than one new electron, and thus a cascade of multiplying electrons is created."*

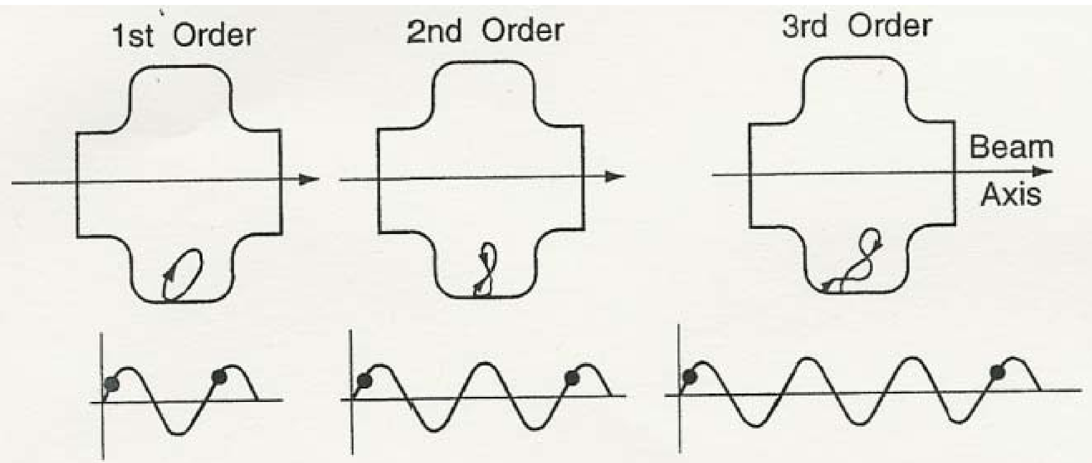
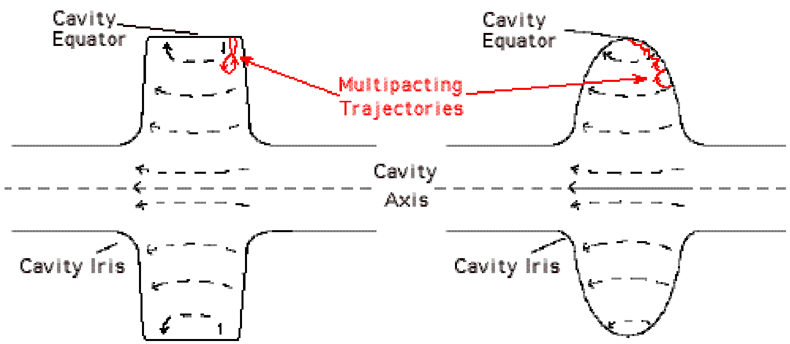


Figure 10.7: Typical one-point multipacting trajectories for orders one, two, and three.

* Taken from "RF Superconductivity for Accelerators", Padamsee, Knobloch and Hays

Techniques to Deal with Multipacting

- Do designs that avoid multipacting:
  - Changing the geometry:



* Taken from "RF Superconductivity - A Primer", by Padamsee (http://www.lns.cornell.edu/public/CESR/SRF/BasicSRF/SRFBas12.html)

  - Using different materials
  - Applying coatings (SEY)
  - Shifting multipacting levels (e.g. by biasing)
- RF-conditioning of structures
- Improving surface cleaning procedures (SEY)

Techniques to Deal with Multipacting

Decision Process:

- 1. Experimentally: build, learn, modify
- 2. Analytic/empiric estimates:
    - Scaling laws
        - work for simple geometries (e.g. coaxial lines)
    - local approximations at RF-surfaces
- 3. Full simulations of fields and particles (2D and 3D)

Groups Working on Multipacting

- A variety of groups are working with different the analytic and numerical approaches
- There are similarities in procedures for the simulation approach
- The major part of the presentation will focus on this simulation approach
- The important steps in the simulation procedures will be presented.
- The presently active groups and their techniques will be presented
- The presentation will end with some examples

Analytic/Empirical Approach to Multipacting

- 1-point scaling law in coaxial lines:
  $P_{MP} \sim (f^*d)^4\, Z^1$
- 2-point scaling law in coaxial lines:
  $P_{MP} \sim (f^*d)^4\, Z^2$
- Hatch diagram: MP-levels as function of (f*d)
- CERN (J. Tűckmantel): local parameters from a 2D field map to judge multipacting conditions without particle tracking (WS 89)
- KEK (K. Saito): Empirical formula for 2-point multipacting in elliptical cavities

Simulation Approach to Multipacting

- 2D: gaps, coaxial lines, rotationally symmetric resonators
- 3D: arbitrary shaped resonators, RF-couplers

- Geometry description
- EM-field description (quality of surface field)
- Surface property description (SEY)(accurate knowledge)
- Particle description: location, energy, (re-)emission
- Scanning of parameter space (field levels, particle energies, rf -phases, emission angles)
- Statistics to identify recurrence patterns

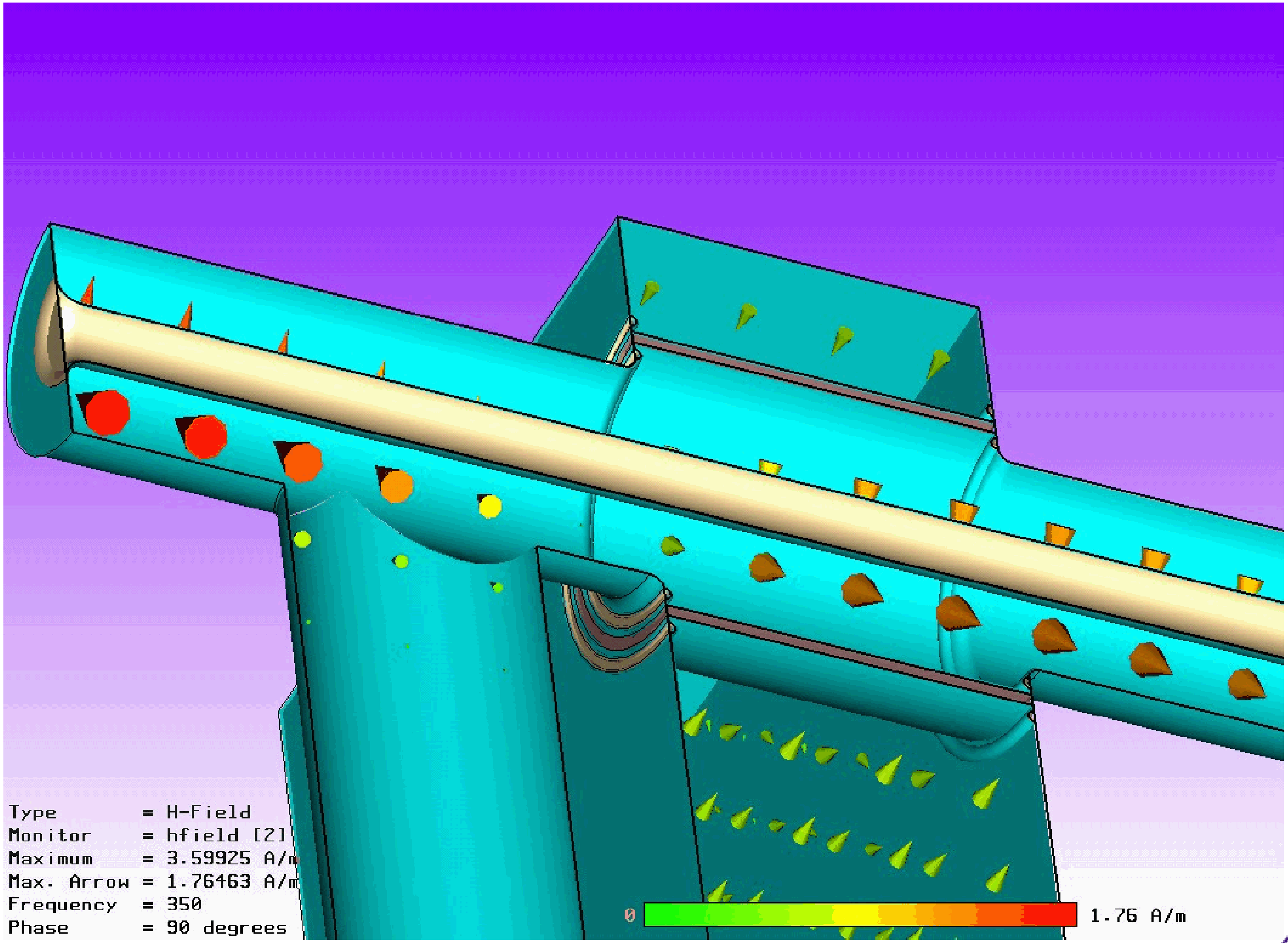
Simulation Approach to Multipacting

Geometry +
EM Field
Description

Statistics to identify
recurrence, multiplication

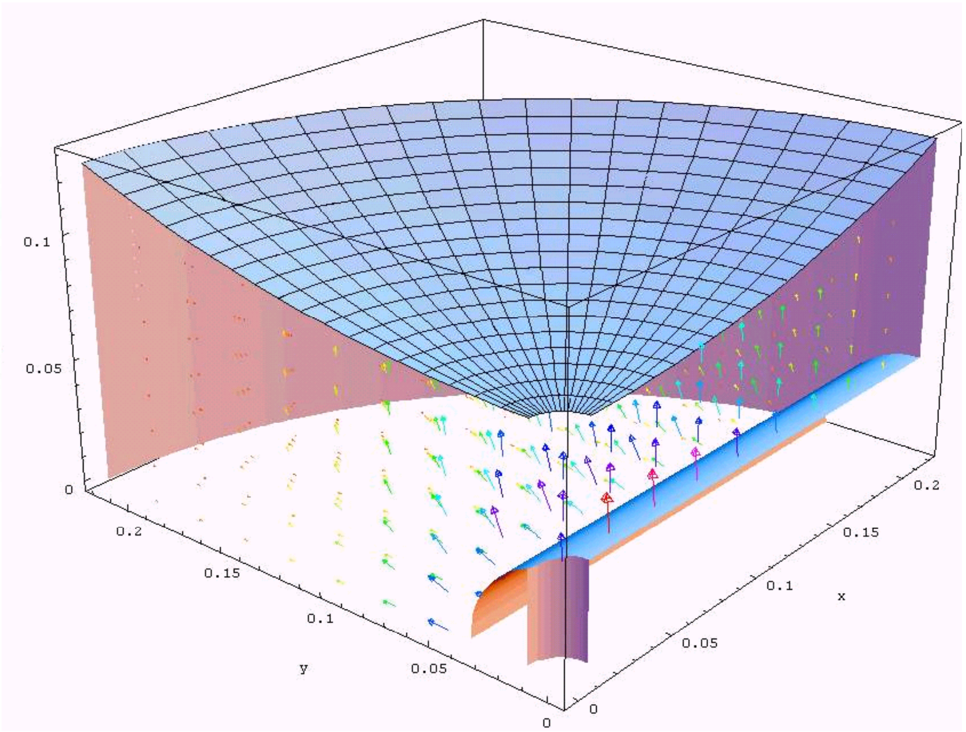
Introduction of particles
and material properties
into original or
processed fields:
Scan parameter space
(particle and field related)
for many particles

Geometry and Fields



Los Alamos
NATIONAL LABORATORY

Surface Field Quality



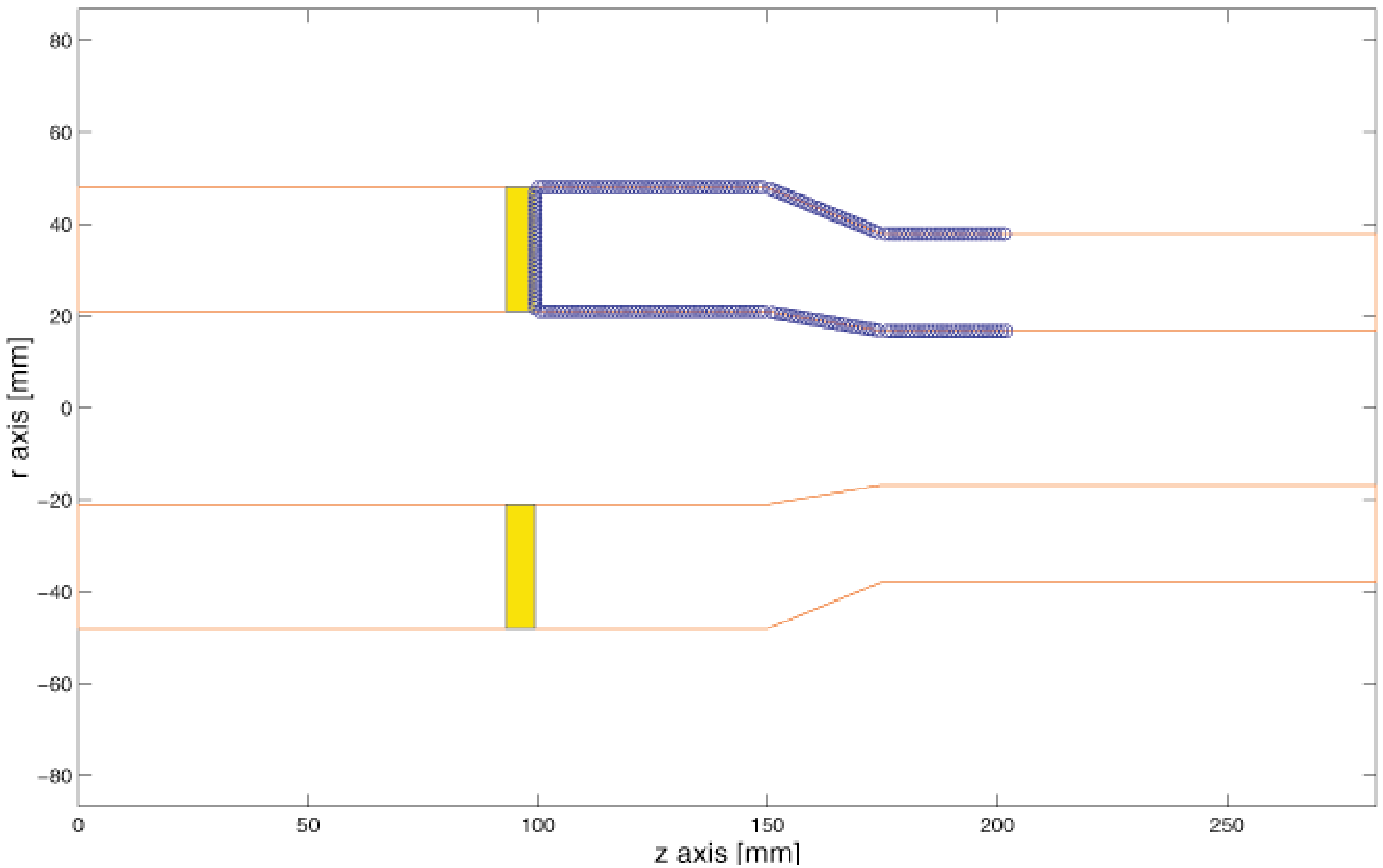
Simulation Approach to Multipacting

Geometry + EM Field Description

Statistics to identify recurrence, multiplication

Introduction of particles and material properties into original or processed fields:
Scan parameter space (particle and field related) for many particles

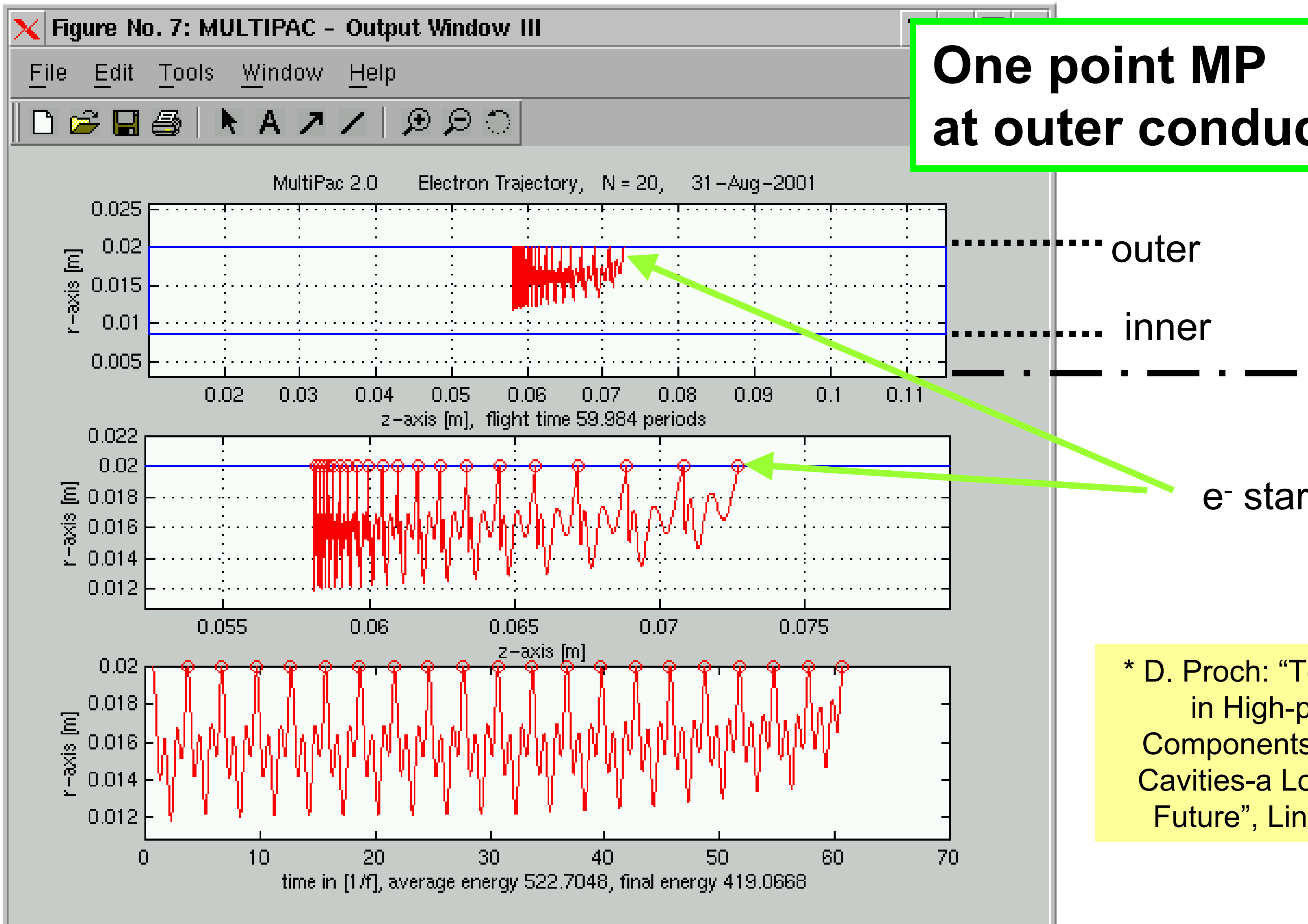
Introduction of Particles



* Taken from work done by P. Ylae-Oijala for the SNS project

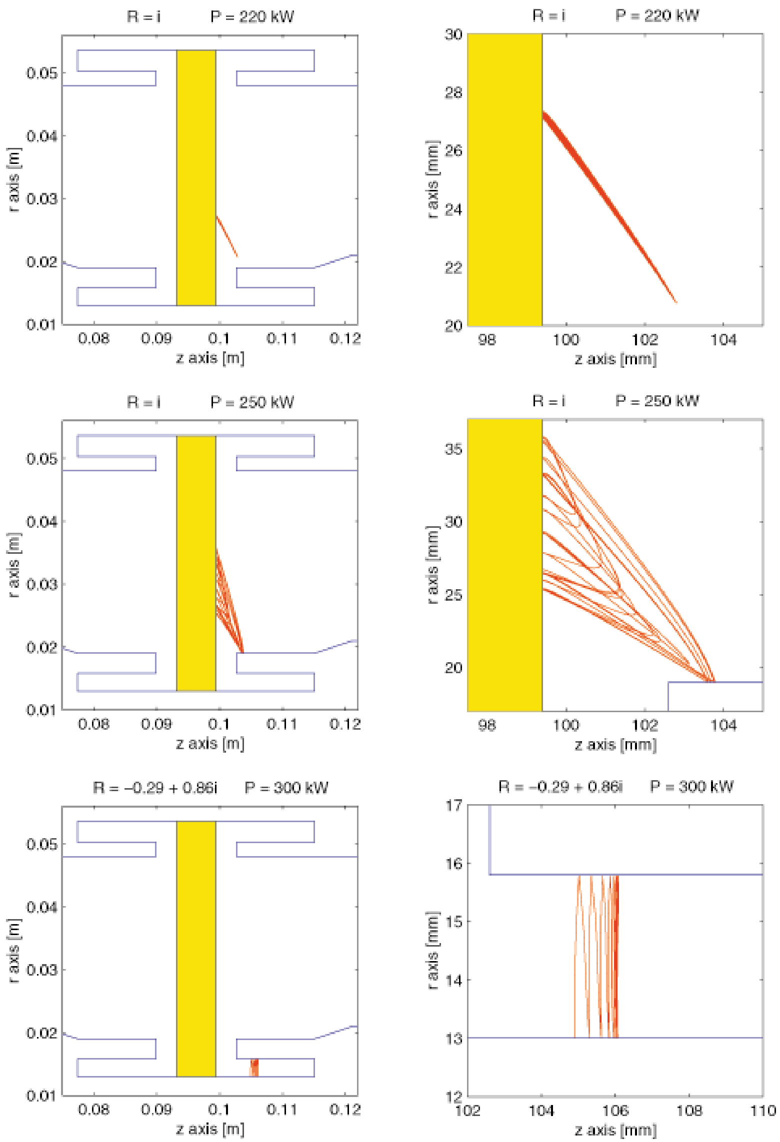
Trajectories: Multipacting in Coaxial Line

One point MP at outer conductor



* D. Proch: "Techniques in High-power Components for SRF Cavities-a Look to the Future", Linac 2002

Trajectories: Multipacting in SNS Window/Choke



* Taken from work done by P. Ylae-Oijala for the SNS project

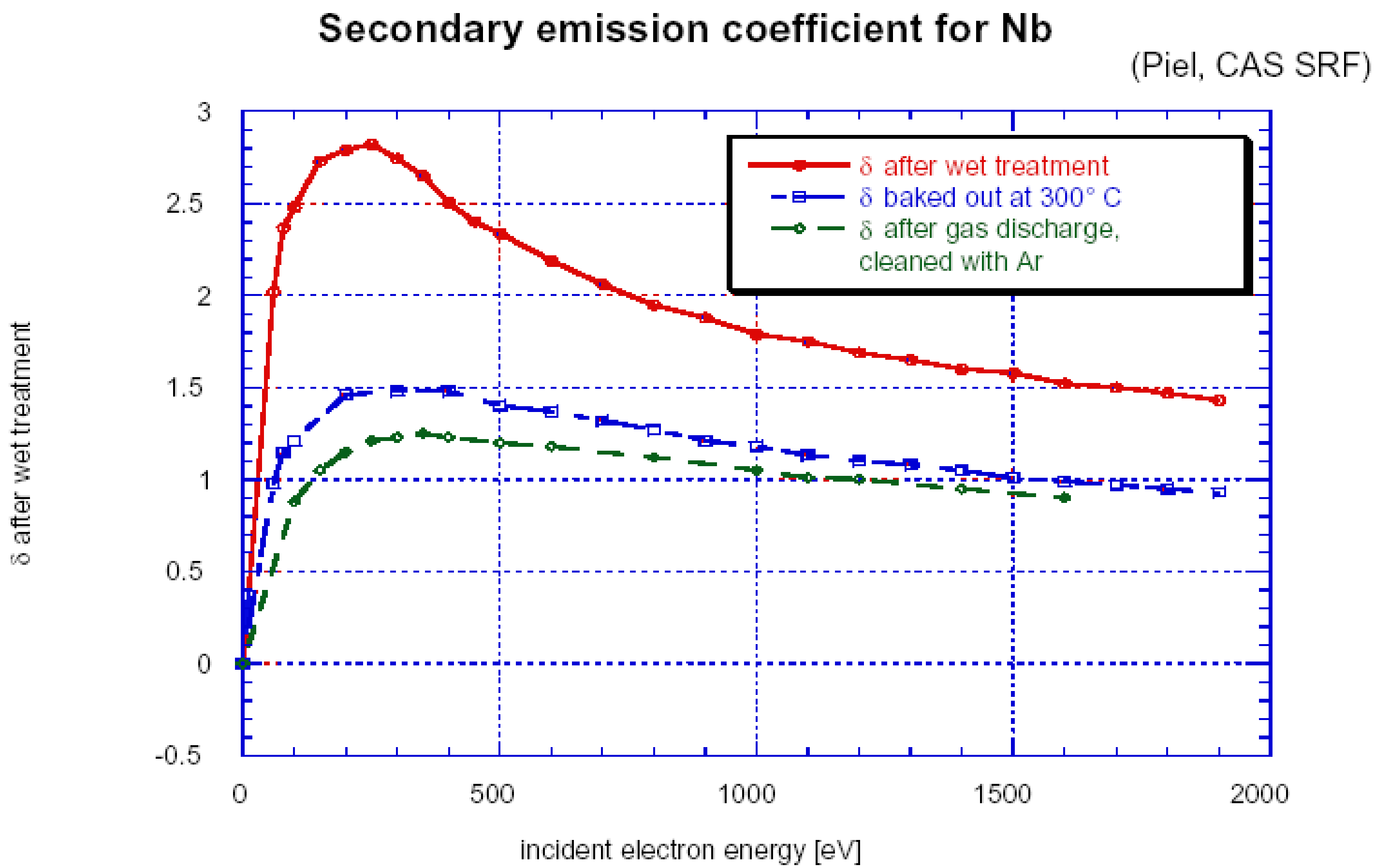
Simulation Approach to Multipacting

Geometry + EM Field Description

Introduction of particles and material properties into original or processed fields: Scan parameter space (particle and field related) for many particles

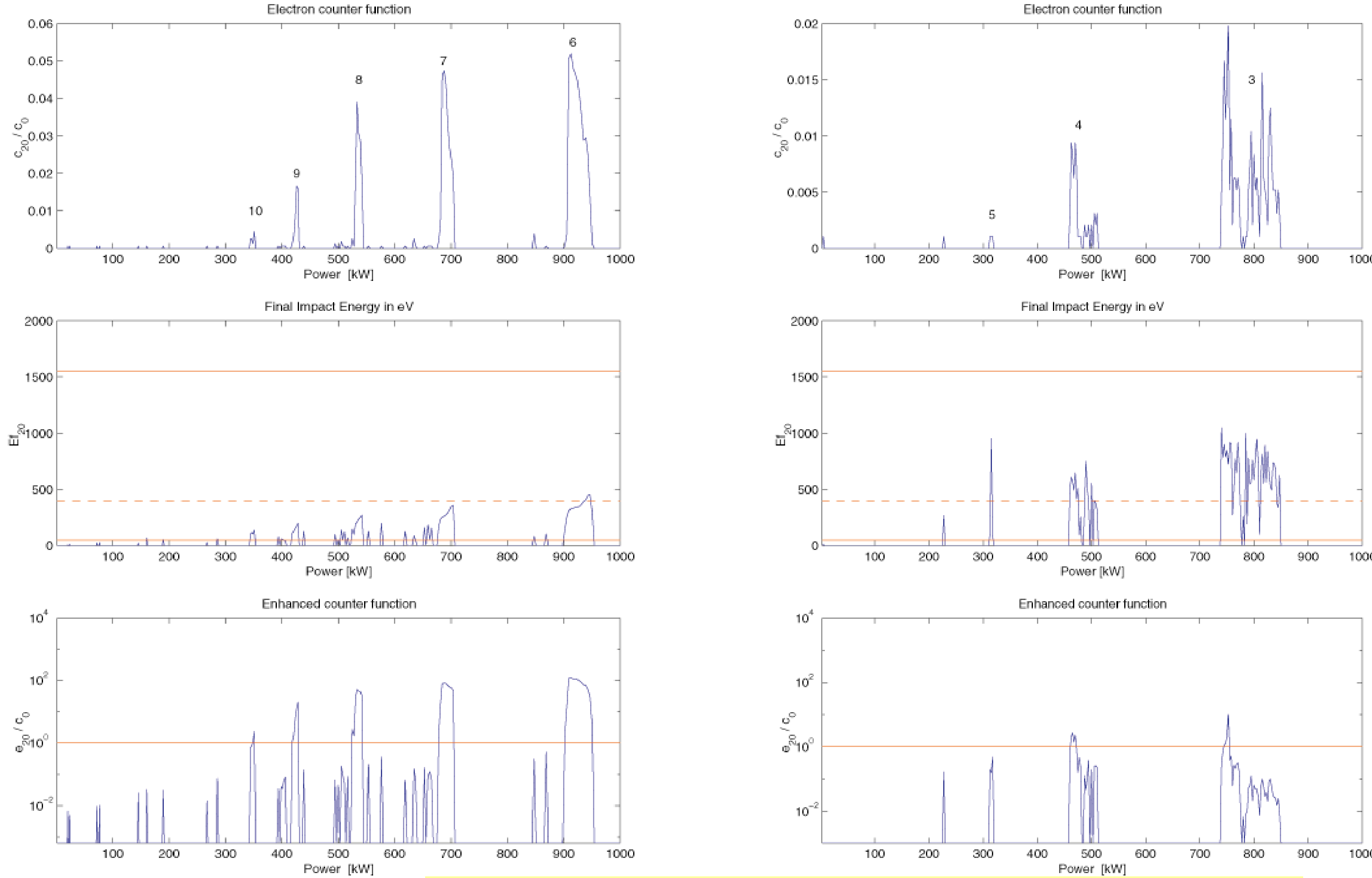
Statistics to identify recurrence, multiplication

Secondary Emission Model



* G. Devanz, CEA Saclay, SFP Meeting in Roscoff in 2000

Statistics



* Taken from work done by P. Ylae-Oijala for the SNS project

Groups Working on Multipacting

	Code	EM Fields	Particles	Emission	Geometry	Scanning	Decisions
Genoa	TRAJECT TWTRAJ	OSCAR2D	Newton	Angle to surface, SE, scattering	2D	E_{kin}, E_a, s, α, ϕ	Spatial or time focusing
Helsinki	MultiPac	Included	RK	Normal to surface, SE	2D/(3D)	E_a, s	Enhanced Counter-functions
Cornell I	MULTIP	SUPERLANS Superfish	Leapfrog	Angle to surface, SE, FE	2D	E_{kin}, E_a, s, ϕ, α	Spatial focusing
Cornell II	XING	MAFIA, analytic SUPERLANS	Leapfrog RK(4th)	Normal to surface, SE	3D/2D	E_a, s, ϕ	Enhanced Counter-functions
Moscow	MULTP	MAFIA	Leapfrog	Angle to surface, SE	3D	E_a, s, ϕ	Phase Focusing
UNM	(TRAK) TRAK-3D	Included	RK	Angle to surface, SE	(2D)/3D	E_{kin}, E_a, s, α, ϕ	Spatial focusing
Saclay	MUPAC	Superfish	RK (4th-5th)	Angle to surface, SE	2D	E_a, s, ϕ	Enhanced Counter-functions

Example: Scaling for Coaxial Line Size

1. Criterium: Multipacting vs. Beam Power:

Single Point MP levels compared between CERN and derived ADTF scenarios

Order	CERN	ED&D-103	ED&D-100	APT-Geo
	352 MHz 75 Ω	350 MHz 75 Ω	350 MHz 75 Ω	350 MHz 50 Ω
7	48 kW	47 kW	42 kW	28 kW
6	52 kW	51 kW	45 kW	30 kW
5	88 kW	86 kW	76 kW	51 kW
4	176 kW	172 kW	153 kW	102 kW
3	234 kW	229 kW	204 kW	136 kW
2	448 kW	438 kW	389 kW	259 kW
1	640 kW	626 kW	556 kW	371 kW

Average Input Power Levels for the Spoke Resonators ($\phi = -30^o$)

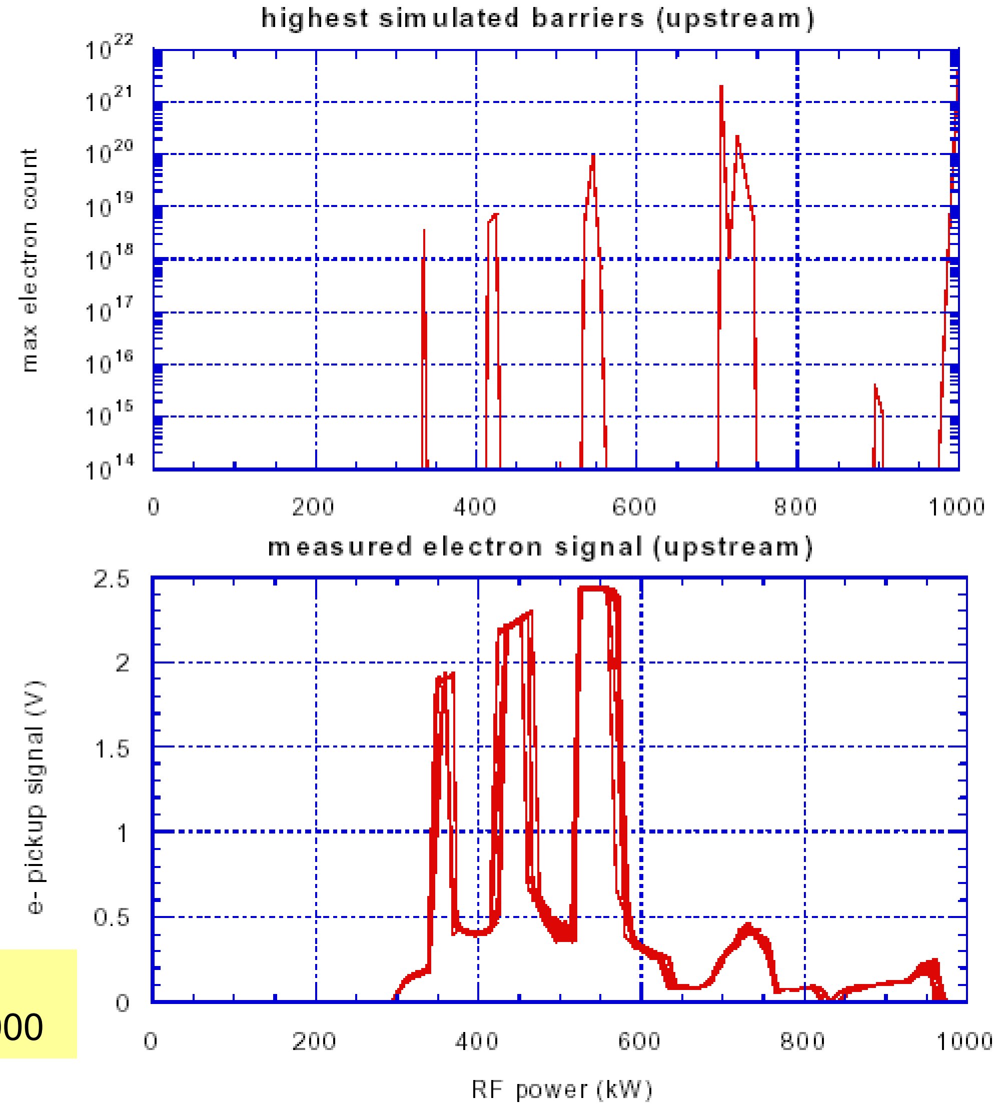
	13.3 mA	100 mA
β=0.175	6 kW	43 kW
β=0.34	19.5 kW	144 kW
for E_0T = 5 MV/m		

	13.3 mA	100 mA
β=0.175	8.5 kW	63.6 kW
β=0.34	28.2 kW	211.8 kW
for E_0T = 7.5 MV/m		

2. Cavity Size: The β=0.175 cavity is limited to coax sizes around approximately 100 mm

Los Alamos NATIONAL LABORATORY

Example: Multipacting Sims vs. Experiment (TESLA)



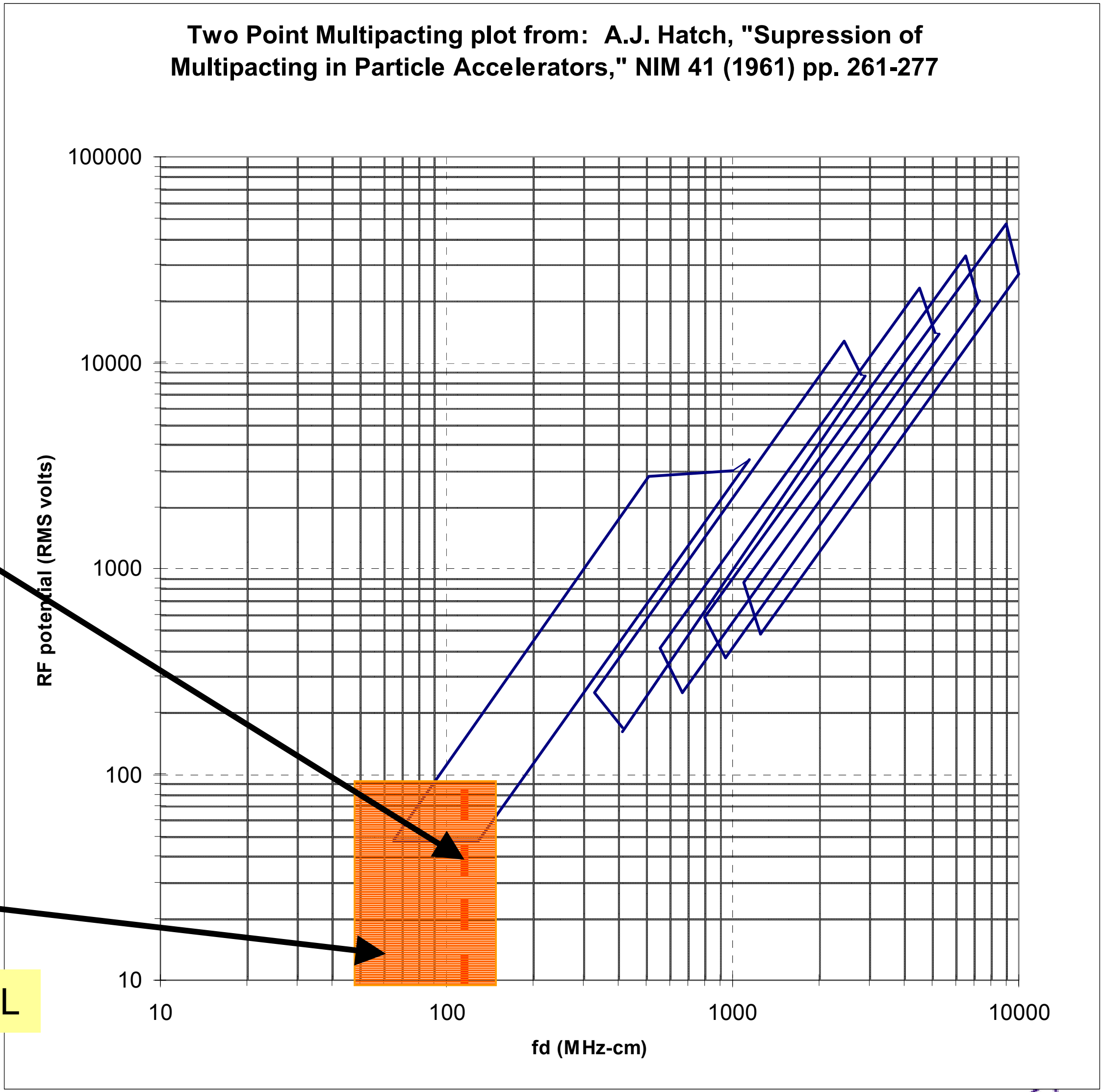
- 1.3 GHz
- 50 Ohms
- 61.6 mm

* G. Devanz, CEA Saclay,
SFP Meeting in Roscoff in 2000

Example: Straight Coax vs. Tapers

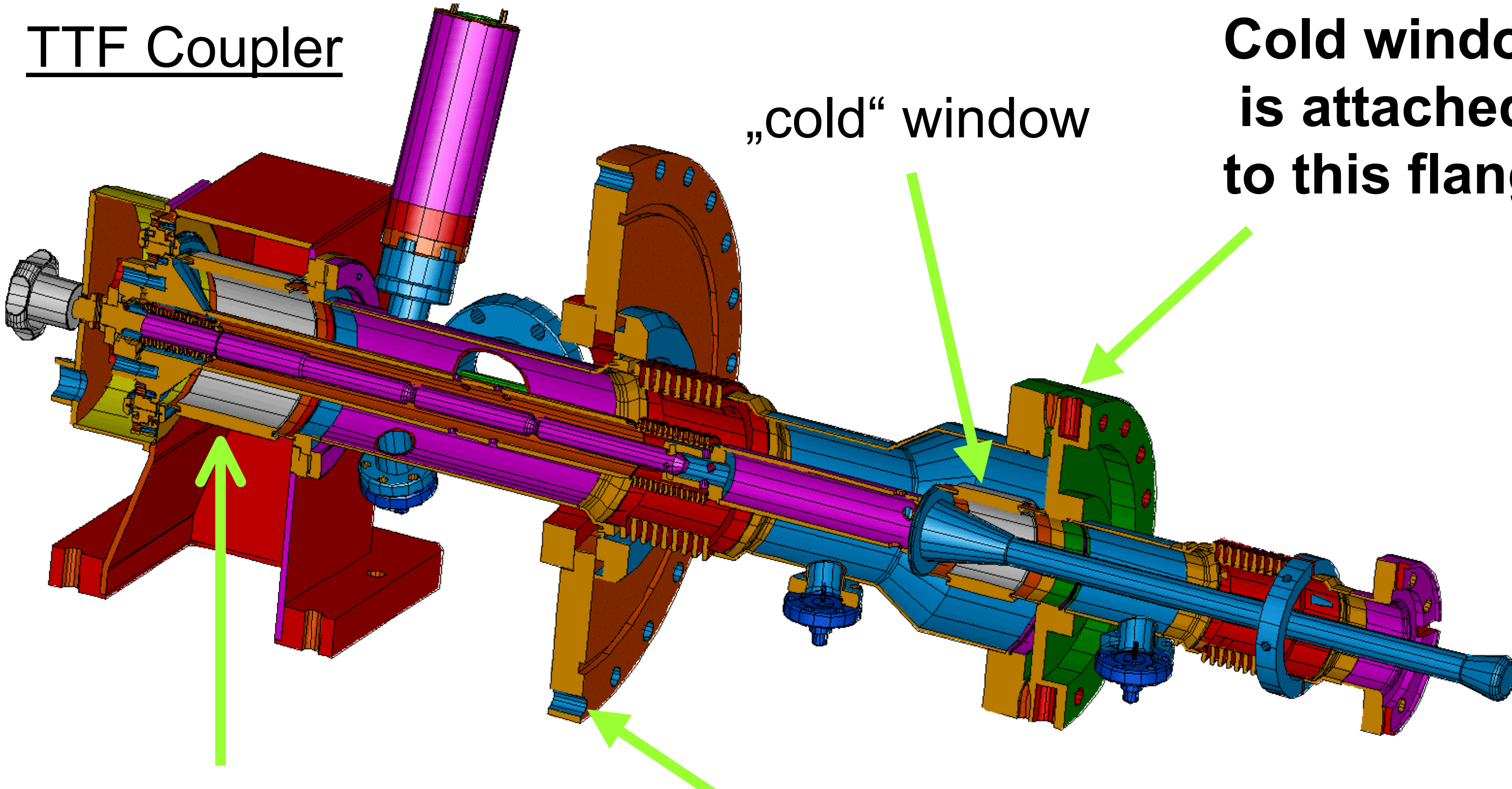
A straight coax marks a single line in the hatch plot. This makes it less probable to have a MP resonance.

A taper has a variable d. Thus is covers a certain area of the hatch plot. Overlap with a MP resonance is more likely.



* Plot provided by B. Rusnak, LLNL

Example: Cold Windows



* D. Proch: “Techniques in High-power Components for SRF Cavities-a Look to the Future”, Linac 2002

Coupler conditioning issues

- Controlled desorption of absorbed gases by multipacting electrons
- Compromise must be found between conditioning speed and sparking risk
- Cold surfaces of couplers for SRF cavities collect cryosorbed gases
  - Warm conditioning does not attack the real enemy
  - Cryosorbed gases might show up more severe after some cold operation
- Conditioning with standing wave (no beam) will not clean all surfaces as probed by traveling wave (beam loading), additional tricks are required

* D. Proch: "Techniques in High-power Components for SRF Cavities-a Look to the Future", Linac 2002

Summary

- Couplers for each application have to be individually adapted.
- Where analytic/empirical approaches are not sufficient, numerical tools (mostly for 2D) do exist and have been successfully benchmarked.
- The basic simulation procedure for existing software has been illustrated.
- Results of simulations have been compared with experimental results.
- Two examples of coupler features that need careful consideration have been shown.

Acknowledgements

Information, graphs, figures and results have been provided by:

- Ricky Campisi and Pasi Ylae-Ojiala for SNS
- Dieter Proch, DESY
- Brian Rusnak, LLNL
- Guillaume Devanz, Saclay
- Hasan Padamsee's group, Cornell
- Gennady Romanov, FNAL